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(54) **PROCESS FOR PRODUCING A NONWOVEN WEB**

(57) **Abstract:**

This invention relates to improved textile-like nonwoven fabrics made from paper fibers and to a process for their preparation using liquid streams.

Much effort has been expended in an effort to make nonwoven fabrics containing a major proportion of paper fibers. Modified papermaking techniques, using blends of short fibers, reinforcing webs, creping, etc., have afforded some improvement but the products are paper-like rather than cloth-like and are characterized by a lack of durability in use, low abrasion resistance and a high stiffness or lack of drape. Similarly, dry formation of such structures by either air deposition or carding systems followed by bonding by suitable solvent or thermally activated binders provide structures having poor drape characteristics.

In accordance with the present invention, it has been found that nonwoven structures produced by papermaking processes can be treated with high pressure jet streams of water to impart greater toughness, flexibility and extensibility, and a surprising resistance to abrasion and surface distortion. These improvements are obtained without use of size or adhesives. Fabrics having a high degree of absorbency, which may be much greater than the untreated starting paper, in combination with desirable textile-like drape, soft hand, surface durability and optical covering power are provided. The products may have a felt-like appearance or may simulate the appearance of a woven fabric.

Embodiments of the invention which consist essentially of paper fibers have a highly entangled fiber structure characterized by a considerable proportion of fiber segments aligned transversely to the plane of the fabric. The relative fiber positions are evaluated by a "90/0 ratio" optical method, described subsequently, and are quite different from the substantially planar fiber

positions previously found in paper. This entanglement provides a lower density, which is softer and more absorbent than conventional paper. These embodiments are characterized by a 90/0 ratio of at least 0.33, a density of less than 0.3 gm./cc., a strip tensile strength of at least 0.7 lb./in. per oz./yd.^{2}, and an elongation-at-break of at least 10% in all directions. Preferred products have strengths of 1.0 lb./in. per oz./yd.^{2} or better. Preferably the elongation-at-break is at least 20%.

Other embodiments contain up to 25% textile staple fibers uniformly distributed through the paper fibers. Stronger products can be provided in this way.

The staple fibers are preferably less than 0.75 inch in length (1.9 cm.) so that the fiber mixture can be processed into paper from a slurry on papermaking equipment. Mixtures containing longer staple fibers can be dry-processed into sheet form by random air deposition methods and then treated with the high pressure jet streams of water.

Any of the above embodiments can be assembled with one or more layers of a different type, e.g., a layer of textile fibers or polyurethane foam, and the assembly traversed with high pressure jet streams of liquid to unite the layers into a laminated structure. By assembling an untreated paper layer on top of the second layer, the paper layer can be treated and united with the second layer in a single operation. A preferred embodiment is prepared by depositing textile fibers to form a layer of randomly oriented fibers, entangling the fibers in the layer by treatment with high pressure jet streams to form a fabric which can readily be used in the next step, assembling the fabric with a layer of paper fibers, and traversing the combination with high pressure jet streams of water to form a laminated fabric characterized by a 90/0 ratio of at least 0.33, a density of less than 0.3

gm./cc., and a strip tensile strength of 1.0 (preferably at least 2.0) lb./in. per oz./yd.^{2}. In this embodiment, the paper fibers provide absorbency and resistance to abrasion, the textile fibers provide improved wet and dry strength, and the combination has desirable drape, softness and covering power.

In forming the laminated embodiments, the layer of textile fibers may consist of any arrangement of the fibers such as woven or knitted fabrics, nonwoven fabrics or loose webs, mats or batts. Non-woven fabrics of staple or continuous filaments may be bonded by resins, fusion, entanglement or needle punching. Loose webs having fibers disposed in random relationship to one another or in any degree of alignment may be used. Combinations of these arrays may be desirable for certain uses. By "textile fibers" is meant fibers and plexifilaments of about 0.5 to 10 denier per filament having a length of at least 6 millimeters. The fibers may be natural or synthetically produced, straight or crimped, or possess a latent ability to elongate, crimp or shrink when heated or given other aftertreatment. In the products of this invention there is a high degree of entangling of the paper fibers with the textile fiber layer, so that the layers are securely held together and perform as a unitary structure in use.

The process of this invention will be better understood from the drawing wherein,

Figure 1 is a schematic side elevational view of one form of apparatus for continuous production of embodiments discussed above, and

Figure 2 is an exploded isometric view of a jet manifold for use in the above apparatus.

The production of fabric with the above apparatus can be summarized as an improvement in the conventional papermaking process of preparing a stock suspension of fibers

in water, continuously screening fibers from the stock to form a wet mat, mechanically removing water from the mat to form a sheet, and drying the sheet; wherein the improvement comprises supporting the sheet on an apertured backing member such as a fine mesh screen, jetting water supplied at pressures of 200 to 2000 pounds per square inch (psi.) to form streams having an energy flux of at least 2300 foot-poundals/in.^{2} second and a diameter of 3 to 10 mils at the treatment distance, traversing the supported sheet with the streams until a stream energy of 0.05 to 2.0 horsepower-hours per pound of product has been applied, optionally continuing the treatment on a relatively coarse apertured patterning member until a stream energy of 0.05 to 1.0 horsepower-hour per pound of fabric has been applied to form a patterned nonwoven fabric, and drying the product.

The high energy flux streams are preferably formed by jetting water, supplied at a pressure of 750 to 1500 psi., from manifolds having orifices of 3 to 5 mils in diameter arranged in a straight line at right angles to the direction of travel of the sheet being treated. The orifices may be spaced 10 or more per inch, and preferably about 30 to 50 per inch. The treatment with the high energy flux streams can be performed at any time after the sheet has sufficient strength to be transferred to a supporting surface for treatment, but is most economically performed prior to the dryers. When forming a laminated fabric, a preformed layer of textile fibers can be fed continuously under the sheet at any convenient location prior to treatment of the assembly with high energy flux streams.

Referring to Figure 1, the portion designated "Fourdrinier" illustrates the basic features of the wet end of a conventional papermaking machine. A suspension of paper fibers is introduced into stuff box 1, from where it flows at a properly controlled rate into mixing box 2.

Water is added at inlet 3 to provide a stock of uniform consistency suitable for the grade of paper to be produced. The stock flows through section 4, where it is screened to remove foreign particles, and into a headbox 5 designed to insure smooth flow and to maintain a uniform mixture. The stock exits from the headbox as a fluid sheet of uniform thickness through slice 6. The stock is received on Fourdrinier wire 7, an endless belt of fine mesh wire screen, which travels continuously over breast roll 8 beneath the slice 6. The wire 7 passes over table rolls 9, around driven couch roll 10 and back to the breast roll. Dandy roll 11 is used to smooth the top surface of the sheet. Suction boxes 12 assist in draining water from the stock to form a wet paper mat. Suction is also applied in the couch roll to lower the water content of the mat to around 80% so the mat will have sufficient strength for removal from the wire.

The wet paper mat is transferred to felt 13 and is passed between press rolls 14 and 15 to remove additional water from the mat. The water is carried away by the felt, which is guided around rolls 16. More water is removed in a second similar press-section, comprising press rolls 17 and 18, felt 19 and felt rolls 20. The press rolls reduce the water content and form a consolidated paper sheet of adequate strength for the jet treating step of this invention.

The portion of Figure 1 designated "Jet Treating" indicates basic features of an apparatus for treating the paper sheet with high pressure streams of water. Two treatment drums 21 and 22 are shown. These have apertured cylindrical surfaces for supporting the sheet. Suction means similar to a suction couch roll is preferably provided for holding the sheet in place and for removing water during treatment. The optional use of a top screen during part of

the treatment is described subsequently but is not shown in order to keep the drawing simple. Supporting felts may also be desirable but are not shown for purposes of clarity. The cylindrical surface of drum 21 may be a suitably supported, fine mesh wire screen. The surface of drum 22 may be the same or may be a coarse screen for imparting a pattern to the paper sheet.

The paper sheet 23 travels from the presses over rolls 24 and is guided onto the surface of drum 21 by roll 25. The drum rotates clockwise and carries the sheet under a plurality of jet-treatment manifolds 26. Only three are shown for simplicity, but a much larger number may be required for high speed operation. The treated sheet passes from drum 21 over a series of guide rolls 27 to the drum 22. This drum rotates counter-clockwise and the sheet is fed onto it so that the treated face is next to the cylindrical surface of the drum. The sheet is carried beneath a plurality of jet-treatment manifolds 28 to treat the face of the sheet opposite to that previously treated. The treated sheet leaves the drum at guide roll 29, passes to press rolls 30 and 31, and is then guided by a series of rolls 32 to the dryers.

The dryers are of the type conventionally used on the dry end of a papermaking machine. The drums 33 are steam-heated and arranged alternately up and down. The treated sheet 34 follows a serpentine path passing over the upper drums and under the lower drums. Blanket felts 35 and 36 hold the treated sheet tightly against the drums and increase the effectiveness of the dryers. After drying, the sheet proceeds to a conventional windup 37.

Figure 2 is a perspective view of a portion of one of the jet-treating manifolds 26 or 28 with the parts separated for clarity. Along the central axis of flat metal strip 40 are equally-spaced jet orifices 41. Above this jet strip is a perforated filter plate 42 which has the same outer dimensions as the jet strip but is curved upward along the central axis so that the plate is spaced away from the jet orifices. The plate is perforated with holes 43 which are no larger than the jet orifices so that particles of foreign matter are caught before they can plug the jet orifices. The holes are uniformly arranged along the curved portion of the plate to provide an even flow of liquid to the different jet orifices. A sufficient number of holes to provide about 3.5% open area produces an even flow without excessive pressure drop through the filter plate.

The manifold body 44 has an undercut portion 45, for receiving the filter plate and jet strip, and has a slot 46 which forms a liquid chamber above the filter plate. Fitting 47 connects to the supply of high pressure liquid. A heavy retainer plate 48 is secured to the manifold body by bolts 49 to hold the filter plate and jet strip in place in undercut portion 45 with a liquid-tight seal. A slit 50 extends along the central axis of the retainer plate to expose the jet orifices.

Equipment for supplying high pressure liquid to the manifold is indicated in Figure 1. Used treating liquid is collected in tank 51 and is withdrawn through drain 52. The liquid passes through filter 53 to remove foreign matter and continues through pipe 54 to pump 55. A multiple-piston, positive-displacement pump powered by

an electric motor 56 is preferred, although other types of pumps can be used. A pulsation dampener 57 is provided in high pressure pump line 58. The high pressure liquid flows from the dampener to a second filter 59 designed to remove any remaining particles of material large enough to plug the jet orifices. A pleated woven screen which will remove any particles larger than 25 microns in size is preferred. The filtered liquid then flows into feed manifold 60 which supplies the jet manifolds. Conventional pressure control and pressure relief valves should be provided for regulating the pressure of individual jet manifolds with safety.

The products of this invention can be prepared from any of the fibers which have previously been used in papermaking. The term "paper fibers" is used herein with reference to fibers having an average length of up to about 4 millimeters, and includes wood pulp, cotton linters and other natural cellulosic fibers, regenerated cellulose, chemically modified cellulosic fibers, synthetic polymer fibrids and very short plexifilament fibers.

For obtaining maximum strength a long fiber wood pulp species (such as kraft), which has been highly refined, is preferred. Excessive beating during refining reduces the maximum tear strength.

For attaining maximum drape and conformability a short fiber pulp (such as hard wood pulp) should be used. It may be desirable for some products to use a blend of several types of wood pulp to optimize physical and aesthetic properties.

Due to the nature of the cellulosic fibers, a varied degree of fibrillation of these fibers occurs during

the hydraulic treatment apart from any previous pulp treatments or linter refining. Such fibrillation further increases the response to continued hydraulic treatment and contributes to such properties as tensile strength and covering power.

Preferably a finely apertured backing member is used as a support during the jet treatment. It may consist of a perforated plate, sheet, woven screen, honeycomb or the like made of any suitable material which is not susceptible to attack by the fluid streams. Plain woven wire screens have been found to be satisfactory. Preferably these will contain from 60 to 200 mesh per inch (per 2.54 cm.). The use of coarser screens affords an increased loss of the small paper fibers and increased problems in reusing the spent wash liquid.

Unless stated to the contrary in the examples, the orifices remain stationary. This produces a fine pattern of very shallow grooves and furrows on the top of the composite web facing the orifices. This effect is reduced when the orifices are oscillated or when the spacing between orifices is decreased.

It may be desirable to reverse the composite web on the support screen so that the original top layer of paper-making fibers faces the screen for a finishing step. This is termed "flipping". A relatively coarse screen can be used for such a finishing step when the fiber structure has been given sufficient integrity in the first treatment. A patterned structure resembling a conventional woven fabric can be produced in this manner. A suitable patterning member may be any screen, perforated or grooved plate which by reason of its apertures and/or surface contours influences

the movement of fibers into a pattern in response to the fluid streams. Included are screens of about 10 to about 30 mesh per inch and perforated plates having less than 250 openings per square inch. The patterning member may have a planar or nonplanar surface or a combination of the two types.

In order to obtain the products of the present invention, the paper fibers must be treated with streams of a non-compressible fluid at a sufficiently high energy flux and for a sufficient amount of treatment to produce a highly entangled fiber structure. The energy flux of a stream in foot-poundals/in.^{2} second is 77 PG/A, where:

P = the liquid pressure in the manifold in psi.,

G = the volumetric flow of the stream in cu.ft./minute, and

A = the cross-sectional area of the stream (in.^{2}) just prior to impact against the web being treated.

The cross-sectional area (A) can be estimated from photographs of the stream with the web removed, or it can be measured with micrometer probes. The energy flux will be satisfactory when P is from 200 to 2000 psi., the orifice diameter of the stream is from 2 to 7 mils and the diameter of the stream is from 3 to 10 mils just prior to impact with the web. The orifices used in the subsequent examples produce streams having over one million energy flux at the pressures shown.

The amount of treatment must be sufficient and is measured by the energy expended per pound of treated product. The energy (E_1) expended during one passage under a manifold in the preparation of a given nonwoven

fabric, in horsepower-hours per pound of fabric, may be calculated from the formula:

$$E_1 = 0.125\ (YPG/sb)$$

where:
- Y = number of orifices per linear inch of manifold,
- P = pressure of liquid in the manifold in psig.,
- G = volumetric flow in cu.ft./min./orifice,
- s = speed of passage of the web under the streams, in ft./min., and
- b = the weight of the fabric produced, in oz./yd.^{2}.

The total amount of energy expended in treating the web is the sum of the individual energy values for each pass under each manifold. Six manifolds are shown in Figure 1 but a much larger number will normally be used in high speed operation. From the formula it will be seen that increasing the speed of passage under a manifold decreases the energy (E_1) by a proportional amount. The total energy expended per pound of product can be increased by using more manifolds to offset the decrease in energy per manifold. The products of this invention are made by the use of a total energy ranging from 0.05 to about 2 HP-hrs./lb. (0.07 to 2.8 Calorie/gram).

The fabrics prepared in accordance with the present invention are stable, coherent, strong and ready for fabric use. If desired, they may be dyed, printed, heat-treated, or otherwise subjected to conventional fabric processing. Thus, for example, they may be treated with resins, binders, sizes, finishes and the like, surface-coated and/or pressed, embossed, or laminated with other materials, such as foils, films or the like.

The products of the present invention have many applications. Thus, they may be employed in the same uses.

as are conventional woven or knitted fabrics. Typical applications include apparel, linings, home furnishings, towels, upholstery and other decorative materials, padding and/or insulating materials, covering materials and the like. They may be laminated to similar sheets or to different materials.

Tests for Evaluating Physical Properties

In the examples, the tensile properties are measured on an Instron tester at 70°F. and 65% relative humidity. Strip tensile strength is determined for a sample 0.5-inch wide, using a 2-inch sample length and elongating at 50% per minute and reported to the nearest 0.1 unit. The 5% secant modulus (termed "modulus") is determined by A.S.T.M. Standards E6-61, part 10, page 1836 and reported as the nearest whole number. Opacity is determined by T.A.P.P.I. Test T425M-60. Density is calculated from thickness measured with Ames thickness gauges, using a pressure of 4.3 psi. (300 g./cm.^{2}) and the fabric weight.

Abrasion resistance is determined using the Tester of the Custom Scientific Co. of Kearney, N.J. (Model CS-149-005) in which a horizontal Silicon Carbide disc (No. 7K disc) rotates on a vertical axis at about 1 revolution/second. A fabric sample is mounted over a resilient backing on a disc parallel to the abrasive disc and attached to a freely rotating vertical shaft that is about one inch off center from the shaft of the abrasive disc. The sample holder is loaded to a total weight of 1000 g. which presses a 1.25-inch diameter portion of the fabric against the abrasive disc. The test is run until failure, by a hole formation, and the time in minutes reported as "abrasion resistance". At 5 minute intervals

during the test, pills or loose debris are blown off the disc so that such material will not ride under the abrading surface and interfere with the test. Unless otherwise stated the results are given for the paper-making fiber face of the product.

The products of this invention possess a soft drape characteristic of woven fabrics. One measure of this is a normalized-for-weight drape flex value of no more than the value of 3.0 (fabric weight/2.0)$^{2/3}$. These values are 2.5 and 3.9 for fabric weights of 1.5 and 3.0 oz./yd.^{2} as compared to values of 4.1 and 4.8 for paper towels and reinforced paper products having these respective weights. Drape flex or bending length is determined by using a sample 1 inch wide and 6 inches long and moving it slowly in a direction parallel to its long dimension so that its end projects from the edge of a horizontal surface. The length of the overhang is measured when the tip of the sample is depressed under its own weight to the point where the line joining the tip to the edge of the platform makes an angle of 41.5° with the horizontal. One-half of this length is the bending length of the specimen, reported in centimeters.

Evaluation of Relative Fiber Positions

The relative fiber positions in papers or fabrics are evaluated by passing light through microtomed sections of these materials. First, a sample of the fabric or paper is embedded in a clear plastic of index of refraction at 6328 Å differing by at least 0.01 from the index of refraction of the fibers in the sample. An axis is fixed arbitrarily on the sample face and a second axis 90° to the

first is then drawn. Sixty consecutive cross-sections are then cut along each axis. The sections are 30 microns thick, 4 mm. wide and 10 mm. long. Out of each group of sixty, the first and every sixth section thereafter are kept and the remainder discarded. The ten retained are glued between two glass slides with the same plastic in which the samples are embedded.

The scanning apparatus consists of:

(1) a source of a collimated, circularly polarized beam of 6328 Å wave length light which is used to illuminate a .8 x 6 mm. area of sample section. A typical source is a helium-neon laser operating in the TEM $_{oo}$ mode, equipped with a quarter-wave plate. The more uniform the light intensity over the .8 x 6 mm. area, the more accurately the relative length can be measured;

(2) a lens;

(3) a thin opaque plate with a narrow slit which is partially blocked by a relatively wide opaque blocking patch perpendicular to the slit;

(4) a second lens similar to the first;

(5) a photocell with a .8 x 6 mm. aperture;

(6) a recorder to pick up the signal from the photocell; and

(7) a projection lens.

The focal length of the lenses, the slit length and width, and blocking patch size are in proper proportion such that the photocell signal from a straight fiber segment goes from maximum to 1/2 value when the fiber is rotated 9 ± 3° from the angle at which the maximum signal occurs.

To effect the measurement, a cross-section is placed one focal length from one of the lenses. One focal length on the other side of that lens is placed the thin plate with the slit. That location is also one focal length from the second lens which is located on the other side of the slit. On the other side of the second lens and one focal length from it is placed the (removable) photocell. The projection lens is placed behind the photocell position.

The light beam is thus directed through a cross-section, first lens, on the blocking patch over the slit (and an equal distance from the edges of the slit), through the second lens and to the photocell or projection lens.

The section image is formed on a screen by the projection lens and the section is aligned with the sample length perpendicular to the slit with a region containing no fiber segments in the .8 x 6 mm. field. The slit is rotated through 90° and the signal from the photocell is recorded when the slit makes an angle of 0° and 90° with the width of the sample. The section is then aligned with the center area of the sample in the .8 x 6 mm. field. If the sample is thicker than .8 mm. then the section is placed with one surface of the fabric just within the .8 x 6 mm. field (regions near the edge of the section are avoided). The signal is recorded with the slit length at an angle of 0° and 90° to the width of the sample. The angles are determined with an accuracy of ± 6° and a precision of ± 1°. The relative light intensity is determined with an accuracy of ± 10% and a precision of ± 2%.

The photocell signal from the sample minus the signal from the clear region is summed at 0° and at 90° for each set of ten sections cut along an axis. The total at 90° is divided by the total at 0°. The smallest value found for the two sets of sections is called the 90/0 ratio. If a sample has a low enough density, the fiber segments in the microtomed sections will be separated from each other and the 90/0 ratio is a measure of the fiber length oriented at 90° to the sample plane, to the fiber length oriented at 0°. If a sample has a high enough density, the fiber segments in the microtomed sections will be compacted and the 90/0 ratio is the ratio of the sample surface area which is oriented at 90° to the sample plane, to the surface area oriented at 0°.

EXAMPLE 1

A sheet of dry wood pulp (Buckeye Paper grade wood pulp P13) with a dry weight of 4 oz./yd.^{2} (135 g./m.^{2}) is supported on a 200 x 200 mesh per inch screen (34% open area) and passed at a speed of 3 ypm (2.7 mpm) under a row of substantially cylindrical, unbroken, vertical jet streams of water. The streams are produced by a row of funnel-shaped orifices spaced 40 per inch (per 2.54 cm.) located in a manifold about 2 cm. above the top of the paper layer. The water enters the cylindrical portion of the orifice 5.0 mils (0.127 mm.) in diameter and about 1 mil (0.025 mm.) long and exits as a stream from the frustro-conical portion which is 11 mils (0.28 mm.) long and has a diameter of about 15 mils (0.38 mm.) at the exit edge of the cone. The following sequence of treatments is used:

Passes	Pressure psi.	($kg./cm.^2$)	Top Screen 14 x 18 mesh with about 65% open area	
2	300	(21)	yes	
2	600	(42)	yes	
2	800	(56)	yes	
2	800	(56)	no	with oscillation

This affords a total treatment of 0.8 HP-hrs./lb. of the product (1.1 Cal./g.).

Properties of the product are given in Table I.

The product is a nonforaminous, soft, flexible fabric with a felt-like appearance but having a fine pattern of very shallow grooves and furrows on one face.

EXAMPLE 2

Kraft bleached wood pulp (Weyerhauser Pulp Co. - Kraft SG-Sulfate) is opened, beaten in water with a Waring Blendor laboratory stirrer for 15 minutes and made into a sheet. The sheet is supported on a 60 x 60 mesh per inch twill-weave wire screen (20% open area) and hydraulically entangled by passing at 8 ypm (7.3 mpm) under a row of water jets. The orifices spaced 40/inch (per 2.54 cm.) have a similar design to that of Example 1, the cylindrical portion having a diameter of 3.5 mils (0.089 mm.). The total treatment consists of 1 pass each at 500, 300 and 600 psi. (35, 18 and 42 $kg./cm.^2$, respectively) to give a total treatment of about 0.1 HP-hrs. per pound of product (0.2 Cal./g.).

Properties of the product are given in Table I.

The product has a fine pattern of very shallow grooves and furrows on one face and a replica of the screen

pattern on the other face. When viewed against a light, a regular pattern of holes is visible. The product has a soft tactile hand and because of its appearance and drape resembles a textile woven fabric.

EXAMPLE 3

A sheet of the wood pulp of Example 1 of 7.2 oz./yd.^{2} dry weight (249 g./m.^{2}) is supported on a 100 x 100 mesh per inch screen (34% open area) and passed at 3 ypm (2.7 mpm) under water jets from a row of the orifices of Example 1 spaced 20 per inch (per 2.54 cm.) for the following treatments:

Passes	Pressure psi.	Pressure (kg./cm.^{2})	Top Screen
2	500	(35)	yes
2	1000	(70)	yes
2	1000	(70)	no

The sample was then flipped and the above sequence repeated to give a total treatment of 0.8 HP-hrs./lb. (1.1 Cal./g.).

The jets were oscillated for the second pass at each pressure. Properties of the product are given in Table I. The product is a nonforaminous, soft, flexible fabric with a felt-like appearance but having a fine pattern of very shallow grooves and furrows on one face.

EXAMPLE 4

A blend of approximately 20% of rayon staple fibers, 1.25 dpf with a length of 2 inches (5.1 cm.), and 80% of opened wood pulp of Example 2, is formed into a web on a laboratory scale random web former. The resulting web is placed on a 50 x 50 mesh per inch (per 2.54 cm.) screen (20% open area) and hydraulically entangled using the apparatus and speed of Example 2 by the following sequence:

Passes	Pressure psi.	(kg./cm.^{2})	Top Screen
1	300	(21)	yes
2	600	(42)	no
1	700	(49)	no

for a total treatment of about 0.2 HP-hrs./lb. (0.3 Cal./g.).

Properties of the product are given in Table I. The product has a fine pattern of very shallow grooves and furrows on one face and a slight, embossed-like replica of the screen pattern on the other face. When viewed against a light, a regular pattern of small holes is visible.

EXAMPLE 5

An aqueous dispersion containing 80% of the wood pulp of Example 1 and 20% 0.25-inch (6.3-mm.) long rayon staple of 1.5 dpf. is used to form a sheet. The sheet is supported on an 80 x 80 mesh per inch (per 2.54 cm.) screen (19% open area) and passed at 3 ypm (2.7 mpm) under a row of water streams from a row of funnel-shaped orifices having a 3.0 mil (0.076 mm.) diameter cylindrical section and spaced 40 per inch (per 2.54 cm.) by the following sequence:

Passes	Pressure psi.	(kg./cm.^{2})	Top Screen
2	400	(28)	yes
2	600	(42)	yes
2	800	(56)	yes

The sample was then flipped and the above sequence repeated for a total treatment of about 0.4 HP-hrs./lb. (0.6 Cal./g.).

Properties of the product are given in Table I. The product is a nonforaminous, soft, flexible fabric with a felt-like appearance but having a fine pattern of very shallow grooves and furrows on one face.

EXAMPLE 6

An aqueous dispersion containing 80% of a kraft wood pulp and 20% of 0.375-inch (9.5-mm.) long, 1.5 dpf rayon staple is used to form a sheet. The sheet is supported on a 180 x 180 mesh per inch (per 2.54 cm.) screen (37% open area) and passed at 10 ypm (9.2 mpm) under water streams of the apparatus of Example II by the following procedure:

Passes	Pressure psi.	Pressure (kg./cm.^{2})	Top Screen	Jets Oscillated
1	500	(35)	yes	yes
1	1000	(70)	yes	yes
1	1000	(70)	no	no

The sample was then flipped and further treated as follows:

1	1000	(70)	no	yes

for a total treatment of about 0.2 HP-hrs./lb. (0.3 Cal./g.) to make product A.

The above procedure is repeated substituting 0.75-inch (1.9-cm.) long rayon staple for the shorter rayon above to make product B. A sample of B is then placed on a 20 x 20 mesh per inch (per 2.54 cm.) screen (19% open area) and hydraulically treated following the same general procedure for an additional 0.06 HP-hrs./lb. (0.085 Cal./g.) to yield product C.

Products A and B have the appearance of a felt material. Product C more nearly resembles a woven fabric with a pattern of apertures of about 5 - 7 mm. in diameter.

TABLE I

Example	Fabric Weight oz/yd2 (g./m2)	Strip Tensile MD x CD lb/in//oz/yd2 (g/cm//g/m2)	Elongation MD x CD %	Modulus MD x CD lb/in//oz/yd2 (g/cm//g/m2)	90/0 Ratio	Density g/cm3	Drape Flex cm MD x CD	Opacity %	Abrasion Resistance minutes
1	2.7 (92)	0.8 (4.2)	37		0.83	0.14			8
2	2.6 (88)	1.0 x 1.2 (5.3 x 6.3)	24 x 23	12 x 11 (64 x 58)	0.42	0.11	3.4	80	2.9
3	5.9 (196)	1.6 (8.5)	52	7 (37)	1.1	0.15	3.6	88	> 110
4	2.6 (88)	2.3 x 1.8 (12 x 9.5)	43 x 55	4 x 4 (21 x 21)	0.38	0.12	3.6 x 3.5	67	5.4
5	5.3 (180)	1.8 (9.5)	43	9 (48)	0.78	0.18	3.6	89	>35
6A	1.8 (61)	0.9 x 0.9 (4.8 x 4.8)	40 x 30	3 x 7 (16 x 37)	0.48	0.14	2.2 x 2.9	69	4
6B	1.7 (58)	1.2 x 1.2 (6.3 x 6.3)	31 x 36	8 x 7 (42 x 37)	0.45	0.14	2.1 x 1.7	73	1
6C	2.0 (68)	1.1 x 0.9 (5.8 x 4.8)	32 x 32	7 x 5 (37 x 26)	0.63	0.13	1.7 x 1.9	66	-

EXAMPLE 7

Rayon fibers of 1.56-inch (3.94-cm.) length and 1.5 dpf are made into a web having a weight of 0.7 oz./yd.^{2} (24 g./m.^{2}) of randomly oriented fibers by an air deposition process using a Rando-Webber machine (made by Curlator Corporation of East Rochester, N.Y.).

The above web is placed on a 60 x 60 mesh screen, covered with a sheet of a commercial saturation paper made of soft wood pulp having a dry weight of 1.9 oz./yd.^{2} (64 g./m.^{2}) and passed at a speed of 8 ypm (7.3 mpm) under a row of substantially cylindrical, unbroken vertical jet streams of water. The streams are produced by a row of funnel-shaped orifices spaced 40 per inch (per 2.54 cm.) located in a manifold about 2 cm. above the top of the paper layer. The water enters the cylindrical portion of the orifice 3.5 mils (0.089 mm.) in diameter and about 2 mils (0.051 mm.) long and exits as a stream from the frustro-conical portion which is 10 mils (0.25 mm.) long and has a diameter of about 11 mils (0.28 mm.) at the exit edge of the cone. The following sequence of treatments is used:

	Pressure		
Passes	psi.	(kg./cm.^{2})	Top Screen
1	200	(14)	yes
1	600	(42)	yes
1	600	(42)	no
1	800	(56)	no

This affords a total treatment of about 0.1 HP-hrs./lb. of the product (0.2 Cal./g.).

Properties of the product are given in Table II.

EXAMPLE 8

The procedure of Example 7 is repeated with the exception that the rayon staple web is hydraulically entangled for a total energy of 0.3 HP-hr./lb. at pressures not exceeding 800 psi. (56 kg./cm.^{2}) before it is assembled as the bottom side of a composite web. The composite web is hydraulically entangled using the equipment and procedure of Example 7, using 1 pass at 300 psi. (21 kg./cm.^{2}) with the top screen and a second pass at 800 psi. (56 kg./cm.^{2}) without a top screen for a total treatment of 0.06 HP-hrs./lb. of product (0.085 Cal./g.).

Properties of the product are given in Table II.

EXAMPLE 9

Woven cotton tobacco cloth weighing 0.45 oz./yd.^{2} (15 g./m.^{2}) is covered with a sheet of a paper (density 0.39 g./cm.^{3}) made from a soft wood pulp (Buckeye P13) weighing 1.8 oz./yd.^{2} (61 g./m.^{2}) and the composite web hydraulically entangled using the equipment and speeds of Example 7 for 1 pass at 500 psi. (35 kg./cm.^{2}) with a top screen and 2 passes at 800 psi. (56 kg./cm.^{2}) without a top screen for a total treatment of about 0.2 HP-hrs./lb. of product (0.3 Cal./g.).

Properties of the product are given in Table II.

EXAMPLE 10

A urethane foam sheet 0.25-inch (6.3-mm.) thick with a weight of 2.2 oz./yd.^{2} (75 g./m.^{2}) is covered with 2 sheets of a commercial paper hand towel having a dry weight of 1.45 oz./yd.^{2} (49 g./m.^{2}) per sheet. The composite web is placed on a 20 x 20 mesh screen and passed

at 2 ypm (1.8 mpm) under streams of water. The streams are produced by a row of funnel-shaped orifices spaced 40 per inch (per 2.54 cm.) located in a manifold about 2 cm. above the top of the web. The water enters the cylindrical portion of the orifice 5 mils (0.13 mm.) in diameter and about 1 mil (0.025 mm.) long and exits as a stream from the frustro-conical portion which is 11 mils (0.28 mm.) long and has a diameter of about 15 mils (0.38 mm.) at the exit edge of the cone. The sequence of treatment follows:

Passes	Pressure psi.	Pressure (kg./cm.^{2})	Top Screen
1	500	(35)	yes
1	1000	(70)	no
1	800	(56)	no
1	1000	(70)	no

This gives a total treatment of 1.4 HP-hrs./lb. of product, (2 Cal./g.). Properties of the product are given in Table II. The product has a very abrasion resistant surface with fabric-like tactile aesthetics.

EXAMPLE 11

The starting layer of textile fibers is a 1.8 oz./yd.^{2} (61 g./m.^{2}) weight web containing 88% of poly-(ethylene terephthalate) continuous filament of 3 dpf with a potential self-elongation of 8 - 10% and 12% of poly-(ethylene isophthalate/terephthalate) copolymer continuous filaments of 2.3 dpf. The web is prepared by the process of British Patent No. 932,482 and has been compressed at about 100°C. to consolidate the web without fusing the copolymer binder filaments. The web is hydraulically entangled to a strong nonwoven by treatment on a 40 mesh

(21% open area) screen with streams from the 5 mil diameter orifices of Example 10 for a total of 2.2 HP-hrs./lb. (3.1 Cal./g.).

A sheet of kraft paper with a dry weight of 2.7 oz./yd.^{2} (92 g./m.^{2}) is placed on top of the above entangled web and screen and passed under the above water streams at 2 ypm (1.8 mpm) as follows:

Passes	Pressure psi.	Pressure (kg./cm.^{2})	Top Screen
2	300	(21)	yes
2	600	(42)	yes
2	1000	(70)	yes
2	1000	(70)	no

This affords a total energy of 1.4 HP-hrs./lb. for the composite structure. The nonwoven fabric is dried and then ironed with a hand iron using "Linen" setting to melt the binding fibers.

The product has a remarkable abrasion resistance of over 270 minutes. For comparison, the initial (unentangled) polyester fiber web after bonding by ironing has an abrasion resistance of only 7 minutes.

Properties of the product are given in Table II.

EXAMPLE 12

High wet modulus rayon (dry tenacity 4.9 gpd, wet tenacity 3.4 gpd) staple of 1.25 dpf and 2-inch (5.1-cm.) length is made into a randomly oriented web of 0.3 oz./yd.^{2} (10 g./m.^{2}) weight.

The above textile fiber web is placed on a 150 x 150 mesh screen, covered with a layer of kraft paper with a dry weight of 1.0 oz./yd.^{2} (34 g./m.^{2}) and passed at 2 ypm

(1.8 mpm) under the water streams of the orifices of Example 7 according to the following schedule:

Passes	Pressure psi.	Pressure (kg./cm.^{2})	Top Screen
1	400	(28)	yes
1	500	(35)	no
web flipped			
1	500	(35)	no

for a total energy of 0.4 HP-hrs./lb. (0.56 Cal./g.).

The above non-foraminous web is then placed on a 20 x 20 mesh screen (19% open area) with the paper face up and passed twice under the streams at 500 psi. (35 kg./cm.^{2}) with the orifices oscillating for a treatment energy of 0.25 HP-hrs./lb. (0.35 Cal./g.). The product is a foraminous nonwoven having a square pattern of apertures about 5-7 mm. in diameter. Properties are given in Table II.

If one attempts to make the above product directly by doing all of the hydraulic treatment on the coarse screen with the same total energy input, it is found that the product is significantly weaker than above and that a significant amount of paper fibers are washed away.

EXAMPLE 13

A randomly oriented web of 0.5 oz./yd.^{2} (17 g./m.^{2}) weight containing polyester staple of 1.5-inch (3.8-cm.) length and 1.5 dpf is placed on a 60 x 60 mesh screen. It is covered with a sheet of soft wood pulp paper having a dry weight of 1.6 oz./yd.^{2} (54 g./m.^{2}) and hydraulically entangled using the water streams and

sheet velocity of Example 7, by the following sequence:

Passes	Pressure psi.	(kg./cm.^{2})	Top screen
1	500	(35)	yes
1	600	(42)	no
1	300	(21)	yes
1	600	(42)	no

The total treatment energy is 0.14 HP-hrs./lb. (0.2 Cal./g.). Properties of the product are given in Table II.

EXAMPLE 14

(a) A random web of the rayon fibers of Example 12, with a weight of 0.5 oz./yd.^{2} (17 g./m.^{2}), is placed on a 150 x 150 mesh screen (37% open area) and covered with a sheet of kraft paper /tensile strength of 4.2 lb./in. per oz./yd.^{2} (22 g./cm. per g./m.^{2}) and 3% elongation/ with a dry weight of 2.0 oz./yd.^{2} (68 g./m.^{2}) and passed at 10 ypm (9.1 mpm) under water streams from the orifices of Example 7 as follows:

Passes	Pressure psi.	(kg./cm.^{2})	Top Screen
1	1200	(84)	yes
2	1500	(105)	no
web flipped			
1	1500	(105)	no

for a total energy of about 0.3 HP-hrs./lb. (0.5 Cal./g.). The properties of the product are reported in Table II and include an excellent value for abrasion resistance of 30 minutes. The product is laundered and tumble-dried in a conventional household combination machine, using a cotton

setting, without noticeable effect on its appearance or utility as a fabric.

(b) The above procedure is repeated with the substitution of a sheet of kraft paper with a dry weight of 1 oz./yd.^{2} (34 g./m.^{2}) for the heavier paper in (a) and the addition of a layer of the 1 oz./yd.^{2} paper beneath the rayon web. Properties of the product are given in Table II. It should be noted that this particular technique gives a 12% loss of the starting fibers. The product has an abrasion resistance of 20 minutes.

EXAMPLE 15

A randomly oriented web of the rayon staple of Example 7 is hydraulically entangled at up to 700 psi. on a 20 x 20 mesh screen (19% open area) to give a nonwoven fabric of 1 oz./yd.^{2} (34 g./m.^{2}) weight.

(a) A sheet of soft wood pulp paper of Example 9 with a dry weight of 3 oz./yd.^{2} (102 g./m.^{2}) is placed on top of the above rayon nonwoven fabric and the composite passed at 3 ypm (2.7 mpm) under water streams from the orifices of Example 10 while resting on an 80 x 80 mesh screen (13% open area) as follows:

Passes	Pressure psi.	Pressure (kg./cm.^{2})	Top Screen
2	300	(21)	yes
2	600	(42)	yes
2	800	(56)	yes
2	800	(56)	no

for a treatment of about 0.8 HP-hrs./lb. (1.1 Cal./g.) to give item (a).

(b) The procedure is repeated to make item (b) with the substitution of a web containing 20% of 0.25-inch (6.3-mm.) rayon fibers and 80% wood pulp for the 100% wood pulp layer used for item (a).

Properties of the products are given in Table II.

(c) In a similar way, a product is prepared in which the paper layer is sandwiched between two outer layers of textile fibers. The product has high absorbency and a soft textile hand. It is suitable for use as a towel, or for absorbent pads.

TABLE II

Example	Fabric Weight oz/yd² (g./m²)	Strip Tensile MD x CD lb/in//oz/yd² (g/cm//g/m²)	Elongation MD x CD %	Modulus MD x CD lb/in//oz/yd² (g/cm//g/m²)	90/0 Ratio	Density g/cm³	Drape Flex cm	Opacity %	Abrasion Resistance minutes
7	2.4 (81)	2.3 x 2.9 (12 x 15)	44 x 53	12 x 7 (63 x 37)		0.14	3.7 x 3.0	69	0.5
8	2.3 (78)	3.2 x 2.3 (17 x 12)	37 x 62	13 x 4 (69 x 21)	0.52	0.13	3.5 x 3.0	67	1.5
9	3.6 (122)	4.2 x 3.1 (22 x 16)	45 x 48	5 x 4 (26 x 21)	0.62	0.14	3.0 x 2.6	71	3.0
10	2.8 (95)	1.0 (5)	67	2 (10)	0.71	0.09	3.7	96	7.8
11	3.7 (126)	5.2 x 5.2 (27 x 27)	128 x 142	12 x 11 (63 x 58)	0.44	0.13	3.8	77	270
12	1.4 (47)	2.6 x 2.0 (14 x 11)	37 x 47	10 x 7 (53 x 37)	0.70	0.08	2.6 x 2.7	44	
13	2.1 (71)	2.3 x 2.2 (12 x 12)	41 x 37	8 x 8 (42 x 42)	0.58	0.13	2.1 x 1.8	69	4.8
14a	2.5 (85)	3.4 x 2.9 (18 x 15)	45 x 53	8 x 4 (42 x 21)		0.17	2.5 x 2.5	79	30
14b	2.2 (75)	2.8 x 2.9 (15 x 15)	33 x 45	10 x 8 (53 x 42)					20
15a	3.8 (129)	1.4 x 1.7 (7.4 x 9)	39 x 54	2 x 3 (11 x 16)	0.72	0.15	2.1	81	10
15b	4.3 (146)	2.5 x 1.8 (13 x 10)	47 x 42	6 x 4 (31 x 21)	0.83	0.19	2.5	84	60

EXAMPLE 16

The starting layer of textile fibers is a 1.6 oz/yd^2 (54 g/m^2) weight web containing 88% of poly(ethylene terephthalate) continuous filaments of 3 dpf (with a potential spontaneous elongation of 12% upon heating at 200°C. or higher) and 12% of the copolymer poly(ethylene isophthalate/terephthalate) (80/20%) continuous filaments of 3 dpf. The random web is prepared by the process of British Patent No. 932,482 and the homopolymer fibers are processed according to U. S. Patent No. 2,952,879 to provide the potential elongation.

The above random web is placed on a 60 x 60 mesh screen (16% open area), covered with a sheet of kraft wood pulp weighing 1.5 oz/yd^2 (51 g/m^2) and a 14 x 18 mesh (65% open area) screen placed on top. The entire assembly is passed under the water streams of Example 10. The top screen is removed and the treatment continued at 1000 and 1500 psi (70 and 105 kg/cm^2) until a total energy of 1.0 HP-hrs/lb is applied to the sample. The fabric is a well entangled product of this invention.

The dry fabric is passed between moving screens through which air at 230°C. is passed to melt the copolymer fiber and further bond the structure. The surface of the fabric that faced the water streams is composed largely ($\geq$75%) of paper fibers, the ends of which are bent down and embedded in the structure. The other side of the fabric has paper fiber ends protruding from the polyester web, which is somewhat rearranged and interpenetrated and entangled by the paper fibers.

The bonded product has the following properties:

Fabric weight	3.1 oz/yd^2	(105 g/m^2)
Density	0.14 g/cm^3	
Strip tensile M.D.	5.7 lb/in//oz/yd^2	(30 g/cm//g/m^2)
C.D.	6.0 "	(32 ")
Modulus, 5% M.D.	20 "	(105 ")
C.D.	13 "	(68 ")
Drape flex M.D. x C.D.	5.8 x 4.8 cm	
Opacity	83%	
Abrasion resistance	56 minutes	
90/0 ratio	0.46	

Since many different embodiments of the invention may be made without departing from the spirit and scope thereof, it is to be understood that the invention is not limited by the specific illustrations except to the extent defined in the following claims.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. The improvement in the conventional paper-making process of preparing a stock suspension of fibers in water, continuously screening fibers from the stock to form a wet mat, mechanically removing water from the mat to form a sheet, wherein the improvement comprises thereafter supporting the sheet on an apertured backing member at a distance from orifices in a manifold which provides water, and jetting water on said sheet, said water supplied to said manifold at pressures of 200 to 2000 pounds per square inch to said orifices to form streams having an energy flux of at least 23,000 foot-poundals/in.^{2} second and a diameter of 2 to 10 mils at the treatment distance from said orifices, traversing the supported sheet with the streams until a stream energy of 0.05 to 2.0 horsepower-hours per pound of product has been applied, and drying the product.

2. The process defined in Claim 1 wherein the sheet is traversed with the streams while supported on a fine mesh screen to produce a felt-like product.

3. The process defined in Claim 1 wherein the sheet is traversed with a stream energy of 0.05 to 2.0 horsepower-hours per pound of product while supported on a fine mesh screen and is then treated with a stream energy of 0.05 to 1.0 horsepower-hour per pound while supported on a coarse apertured patterning memeber to form a patterned product.

4. The process defined in Claim 3 wherein the coarse apertured patterning member is a woven wire screen of about 10 to 30 mesh per inch and the appearance of the product resembles that of a woven textile fabric.

5. The process defined in Claim 1 wherein said fibers consist essentially of 75% to 100% paper fibers and 0% to 25% textile staple fibers by weight.

6. The process defined in Claim 1 wherein said sheet is assembled on top of a layer of textile staple fibers, the assembly is supported on the apertured backing member and the supported assembly is traversed with the streams to form a laminated product.

7. The process of Claim 5 or Claim 6 characterized in that the sheet is dried before being traversed with the water streams.

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FIG. 1

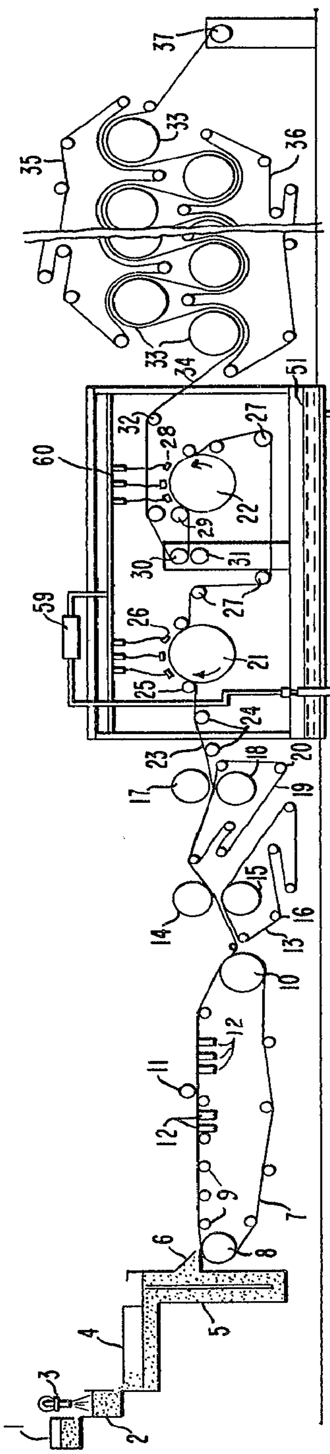
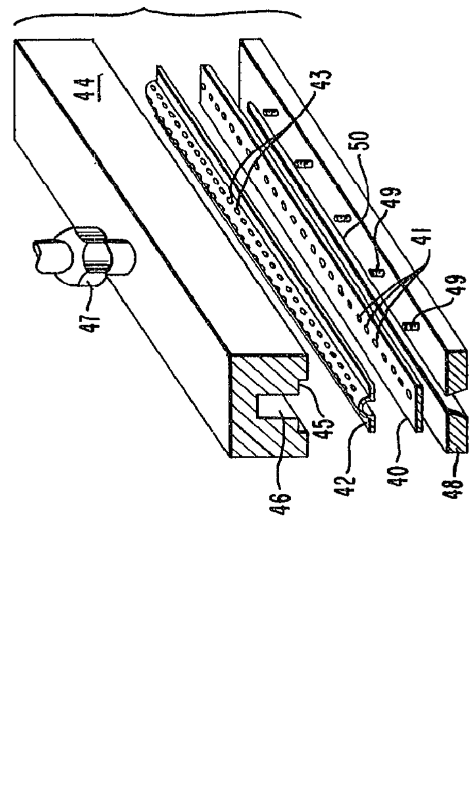


FIG. 2



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